International Journal of Advanced Biochemistry Research 2025; 9(6): 866-873

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating: 5.29
IJABR 2025; 9(6): 866-873
www.biochemjournal.com
Received: 18-04-2025
Accepted: 22-05-2025

Shubham
Department of Vegetable Science, College of Horticulture, Maharana Pratap Horticultural University, Karnal, Haryana, India

VPS Panghal
Department of Vegetable Science, College of Agriculture, CCS Haryana Agricultural University, Hisar, Haryana, India

DS Duhan
Department of Vegetable Science, College of Agriculture, CCS Haryana Agricultural University, Hisar, Haryana, India

Vikas Gill
Department of Vegetable Science, Regional Research Station, Bawal, CCS Haryana Agricultural University, Hisar, Haryana, India

Sarita Devi
Department of Botany and Plant Physiology, College of Basic Science and Humanities, CCS Haryana Agricultural University, Hisar, Haryana, India

Sudesh
Department of Vegetable Science, College of Agriculture, CCS Haryana Agricultural University, Hisar, Haryana, India

Corresponding Author:
Sudesh
Department of Vegetable Science, College of Agriculture, CCS Haryana Agricultural University, Hisar, Haryana, India

Effect of saline water and nitrogen fertigation on some physiological traits of garlic (*Allium sativum* L.)

Shubham, VPS Panghal, DS Duhan, Vikas Gill, Sarita Devi and Sudesh

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i6j.4627

Abstract

The study was undertaken to investigate the influence of saline irrigation and nitrogen fertigation on the growth, yield, and quality of garlic variety HG-17 at the Research Farm of the Soil Science, Department, CCSHAU, Hisar during the *Rabi* seasons of 2021-22 and 2022-23. The experimental design was structured as a split-plot with three replications. The treatments encompassed three levels of saline water (canal water, EC_{iw}=2.5 dS/m, and EC_{iw}=5.0 dS/m) serving as the primary treatments, alongside three nitrogen fertilizer levels (75%, 100% and 125% RDN) as the sub-main treatments. The results showed that the plant height at 30 days after planting (DAP), plant height at 60 days after planting (DAP) and all the physiological traits in leaves *viz*., dry matter content, chlorophyll content, chlorophyll Index and nitrogen balance index were recorded significantly maximum under irrigation with canal water as compared to saline water levels. Among nitrogen levels, the growth and physiological traits increased with increasing nitrogen levels and recorded maximum with 125% RDN applied through drip as compared to lower levels (75% and 100% RDN) of nitrogen during both the years of study, as well as pooled data of two years.

Keywords: Garlic, fertigation, days, nitrogen levels, saline water levels

1. Introduction

Garlic (*Allium sativum* L.) ranks as the second most extensively cultivated bulbous crop subsequent to onion, classified under the family Amaryllidaceae (previously Alliaceae), and is cultivated globally for both culinary and therapeutic applications. (Shukla *et al.*, 2018; Tiwari *et al.*, 2019) [33, 37]. The FAO 2023 report indicates that approximately 28.67 million tonnes of garlic are produced worldwide annually. It is estimated that India's production remains steady at around 3213.93 thousand tonnes, cultivated over an area of approximately 382.61 thousand hectares, positioning it second globally in terms of both land area and production, following China (Anonymous, 2023-2024) [5]. It is extensive, including proteins, amino acids, carbohydrates, dietary fiber, lipids, pectins, and mucilaginous compounds, while also being a notable source of minerals such as calcium, magnesium, iron, and others, as well as vitamins A, PP, C, B1, and B2, with specific macronutrient compositions of 29.0% carbohydrates, 6.3% proteins, 0.3% minerals, and 0.1-0.4% essential oils (Shukla *et al.*, 2018;Najman *et al.*, 2021) [33, 22]. The bioactive compounds in garlic exhibit a spectrum of biological activities such as antiviral, antioxidant, antibacterial, antifungal, and antiprotozoal effects (Lowe *et al.*, 2020; Frazzoli *et al.*, 2023) [20, 15], while also providing anticancer, anti-diabetic, anti-inflammatory, immune-enhancing, and cardioprotective advantages (Bayan *et al.*, 2014;El-Saadony *et al.*, 2024) [8, 12].

Soil salinity poses a critical threat to global agricultural productivity, adversely affecting crop growth and yield while contributing to the rapid degradation of arable land at a rate of three hectares per minute and potentially jeopardizing up to 30% of current food-producing land in the next 25 years, exacerbated by inadequate soil management, saline irrigation, and excessive mineral fertilizer usage, particularly in arid regions with high evapotranspiration rates (Awad-Allah *et al.*, 2020; Cappellari *et al.*, 2023) [7, 32]. In garlic, salinity stress adversely affects growth metrics (Ahmad *et al.*, 2021) [2], with studies indicating adequate growth at soil salinity levels up to 4.14 dSm^{-1}, although total dry matter significantly declines beyond this threshold (Syamsiah *et al.*, 2020) [35]. Plants exhibit physiological responses to salinity, such as the accumulation of reactive oxygen species (ROS) which can adversely affect photosynthetic pigments, increase lipid peroxidation, modify cell membrane permeability, denature proteins, and induce DNA mutations (Chinnusamy *et al.*, 2005; Cappellari *et al.*, 2023) [10, 11] in response, they have developed protective strategies like osmoregulation through compatible solute accumulation (e.g., glycine betaine, proline, amino acids) and various antioxidant systems (Ferchichi *et al.*, 2018) [14], alongside maintaining ion homeostasis via K^+ retention, Na^+ exclusion, and optimal K^+/Na^+ ratios to enhance salinity tolerance (Cai *et al.*, 2020) [9].

High saline irrigation conditions lead to chlorophyll degradation and decreased carotenoid content in garlic and some research suggests that garlic can thrive in soils with salinity up to 3.9 dSm^{-1}, but bulb yield diminishes by 50% at 7.4 dSm^{-1} or 8 dSm^{-1} of saline irrigation water, highlighting critical salt tolerance thresholds for cultivation in saline conditions (Nana *et al.*, 2024) [23]. The salinity induces oxidative stress in garlic through the accumulation of reactive oxygen species (ROS) and cause deterioration of photosynthetic pigments, lipid peroxidation, cell membrane permeability alterations, protein denaturation (Cappellari *et al.*, 2023) [10]. Under high saline irrigation conditions lead to chlorophyll degradation and decreased carotenoid content in garlic (Nana *et al.*, 2024) [23].

In the context of garlic cultivation, the judicious application of nitrogen has been shown to significantly influence the quantitative and qualitative parameters of yield; however, its utilization must be meticulously regulated to prevent diminishing returns and adverse consequences from over-application (Tiwari *et al.*, 2019) [37]. Nitrogen metabolism in plants encompasses essential enzymatic processes such as nitrate reductase, nitrite reductase, and glutamine synthetase, which are crucial for converting absorbed nitrogen into usable forms for amino acid and protein synthesis, thereby significantly impacting plant growth and development (Esmaili *et al.*, 2008; Shahid *et al.*, 2020) [13, 31]. By optimizing nitrogen inputs in terms of both volume and origin, cultivators can enhance yields while preserving the unique quality traits that render garlic an esteemed crop for culinary and medicinal uses. The detailed connection between salinity stress and nitrogen metabolism serves as a key factor in plant physiology that significantly affects crop yield in saline environments, as salt stress alters nitrogen dynamics by obstructing uptake, transport, assimilation, and utilization through mechanisms such as ionic competition, wherein chloride ions (Cl^-) contend with nitrate (NO^-_3) and ammonium (NH^+_4) contests sodium (Na^+), resulting in toxicities and imbalances that adversely impact nitrogen metabolism (Nazir *et al.*, 2023) [24]. In garlic specifically, the interaction between nitrogen and salinity is understanding the intricate relationship between salinity and nitrogen metabolism provides essential knowledge for developing effective management strategies intended to improve crop performance in saline conditions, as the optimization of nitrogen sources, application rates, and timing may mitigate the detrimental effects of soil salinity on the growth and yield of salt-sensitive crops such as garlic (Zayed *et al.*, 2023; Nazir *et al.*, 2023) [39, 24]. In this study, systematically investigated the Effect of saline water and nitrogen fertigation on some physiological traits of garlic.

2. Materials and Methods

The experiment was carried out during the years 2021-22 and 2022-23 at the Research Farm of the Soil Science Department, CCSHAU, located in Hisar, Haryana, situated at an elevation of 215 meters above the average sea level, positioned between $29^0$09’03.5” N latitude and $75^0$41’20.8” E longitude, exhibiting a climate defined by semi-arid conditions. This region is characterized by hot, arid winds in the summer and marked dry weather in the winter. Planting of cloves of garlic variety Hisar Garlic17 was done during the *Rabi* seasons of 2021-22 and 2022-23 was done on the raised beds of with three rows planted on each bed with spacing at 15 cm × 10 cm. The experiment was laid out in a split-plot design with tree replications. The treatment consists of three saline water levels (canal water, EC_{iw}=2.5 dS/m and EC_{iw}=5.0 dS/m) as main treatments and three N fertilizer levels (75%, 100% and 125% RDN) as sub-main treatments. The results showed that the plant height at 30 days after planting (DAP), plant height at 60 days after planting (DAP) and as well as the physiological traits *viz.*, dry matter content, chlorophyll content, chlorophyll Index and nitrogen balance index were recorded significantly maximum under irrigation with canal water as compared to saline water levels during both the years of study, as well as pooled data of two years. The statistical methodology for data analysis is described by Panse and Sukhatme (1967) **[25]** was followed for the analysis and interpretation of experimental results was done using OPSTAT software, developed by CCS HAU, Hisar.

3. Results

3.1 Plant height at 30 days after planting (DAP)

The data on garlic plant height recorded at 30 DAP (Table 1) depicted that different levels of saline water irrigation had significant impacts on plant height, which decreased significantly with increasing saline levels of irrigation water. Among the saline levels of irrigation water, the maximum mean plant height (26.3 and 27.5 cm) was observed under irrigation with canal water, while the minimum mean plant height (19.9 and 21.9 cm) was observed under irrigation with saline water (EC_{iw}= 5.0 dS/m) during 2021-22 and 2022-23 years, respectively. Similarly, two years pooled data of mean plant height at 30 DAP also followed the same trend and significantly highest mean plant height (26.9 cm) was recorded in irrigation with canal water and lowest mean in saline water at 5.0 dS/m (20.9 cm).

Nitrogen fertigation also had significant effect on plant height at 30 DAP, which increased with increasing nitrogen levels. Among all the levels of nitrogen fertigation, the maximum mean plant height (26.1 and 28.0 cm) was recorded with the application of 125% RDN through fertigation, whereas the shortest mean plant height (19.2 and 20.3 cm) was found when 75% RDN was applied via fertigation during 2021-22 and 2022-23 years, respectively. The similar trend was also seen in the two years pooled data on mean plant height at 30 DAP, the significantly higher mean plant height (27.5 cm) was recorded in nitrogen at 125% RDN and lowest mean in 75% RDN (19.7 cm). However, the interaction impact of salinleaf e water and nitrogen fertigation was observed to be non-significant in plant height at 30 DAP during the years 2021-22 and 2022-23, as well as pooled data of both years.

3.2 Plant height at 60 days after planting (DAP)
The data for the height of garlic plants at 60 DAP (Table 2), demonstrated that the plant height was significantly affected by different saline water levels and that this effect reduced significantly throughout the duration of the two years research as saline water levels increased. When compared to saline levels of irrigation water, the maximum mean plant height (39.3 and 40.4 cm) was observed under irrigation with canal water, while the minimum mean plant height (29.8 and 30.6 cm) was observed under irrigation with saline water 5.0 dS/m during 2021-22 and 2022-23, respectively. Similarly pooled data of two years on mean plant height at 60 DAP also followed the same trend and significantly higher mean plant height (39.8 cm) at 60 DAP was recorded in canal water and lowest mean in saline water at 5.0 dS/m (30.0 cm).

Plant height at 60 DAP was significantly impacted by nitrogen fertigation levels and the effects increased with greater fertigation levels. Among all nitrogen fertigation levels, the highest mean plant height (38.7 and 39.6 cm) was recorded with an application of 125% RDN by fertigation, while the smallest mean plant height (29.2 and 29.5 cm) was obtained when 75% RDN was applied via drip irrigation during 2021-22 and 2022-23 years, respectively. Accordingly, two years pooled data on mean plant height at 60 DAP also followed the same trend and significantly higher mean plant height (39.1 cm) at 60 DAP was recorded in nitrogen at 125% RDN and lowest mean in 75% RDN (29.4 cm). However, the interaction between saline water and nitrogen fertigation was found to be non-significant for plant height at 60 DAP in the years 2021-22 and 2022-23, as well as in pooled data of both years.

Table 1: Effect of saline water and nitrogen fertigation on plant height (cm) at 30 DAP in garlic

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	22.0	27.7	29.3	26.3	23.1	28.9	30.4	27.5	22.5	28.3	29.9	26.9
Saline water 2.5 dS/m	19.6	24.5	25.8	23.3	20.7	26.7	27.8	25.1	20.1	25.6	26.8	24.2
Saline water 5.0 dS/m	16.0	20.6	23.2	19.9	17.1	22.8	25.7	21.9	16.5	21.7	24.4	20.9
Mean	19.2	24.3	26.1		20.3	26.2	28.0		19.7	25.2	27.5	
CD at 5%	Irrigation Water (I): 0.9 Nitrogen levels (N): 0.6 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 1.7 Nitrogen levels (N): 1.4 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 0.8 Nitrogen levels (N): 0.7 N at same level of I: NS I at same level of N: NS			

Table 2: Effect of saline water and nitrogen fertigation on plant height (cm) at 60 DAP in garlic

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	33.4	41.9	42.6	39.3	34.7	42.6	43.8	40.4	34.1	42.3	43.2	39.8
Saline water 2.5 dS/m	29.9	36.9	38.9	35.2	28.6	38.1	39.7	35.5	29.3	37.5	39.3	35.4
Saline water 5.0 dS/m	24.2	30.7	34.6	29.8	25.3	31.2	35.2	30.6	24.8	30.3	34.9	30.0
Mean	29.2	36.5	38.7		29.5	37.3	39.6		29.4	36.7	39.1	
CD at 5%	Irrigation Water (I): 1.8 Nitrogen levels (N): 0.9 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 2.2 Nitrogen levels (N): 1.4 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 1.6 Nitrogen levels (N): 1.1 N at same level of I: NS I at same level of N: NS			

3.3 Leaf dry matter (%) at harvest
The data presented in Table 3 shows that dry matter content at harvesting in garlic leaves is influenced significantly by the application of saline water and nitrogen fertigation levels. As the saline water levels increase, there is a decrease in the dry matter content in leaf. Application of irrigation with canal water obtained the highest mean leaf dry matter content at harvesting time (14.76 and 16.63%). While, the lowest mean leaf dry matter content (11.73 and 12.59%) was observed at saline water 5.0 dS/m during 2021-22 and 2022-23 years, respectively. Similarly, two years pooled data of mean leaf dry matter content at harvesting also followed the same trend and significantly highest mean leaf dry matter content (15.70%) was recorded in irrigation with canal water and lowest mean (12.16%) in saline water at 5.0 dS/m.

When applying 125% RDN through fertigation, the garlic leaves exhibited the significantly highest mean leaf dry matter content (14.76 and 16.58%) as compared to lower levels of nitrogen. Conversely, the lowest mean leaf dry matter content at harvest (10.95 and 12.41%) was observed when using 75% RDN as fertigation during 2021-22 and 2022-23, respectively.

Similarly, two years pooled data of dry matter content in leaf at harvest also followed the same trend and significantly higher mean leaf dry matter content (15.67%) in leaf was recorded with 125% RDN and lowest mean (11.68%) in 75% RDN. There is no significant interaction between saline water and nitrogen fertigation was observed for leaf dry matter content during both the years of study as well as in pooled data of two years.

3.4 Chlorophyll content in leaf at 60 DAP
The chlorophyll content in garlic leaves at 60 DAP was strongly affected by different levels of saline water irrigation which increased significantly with decreasing saline levels in irrigation water from saline water 5.0 dS/m to canal water (Table 4). According to the data, the mean chlorophyll content in leaves at 60 DAP was recorded significantly highest (1.63 and 3.07 mg/g FW) under canal water, while the lowest mean chlorophyll content in leaves at 60 DAP (0.98 and 1.57 mg/g FW) under saline water 5.0 dS/m during the years 2021-22 and 2022-23, respectively and similarly the two years pooled data of mean chlorophyll

content also followed the same trend and significantly higher mean chlorophyll content (2.35 mg/g FW) at 60 DAP was recorded in irrigation with canal water and lowest mean chlorophyll content (1.27 mg/g FW) in saline water at 5.0 dS/m.

In terms of nitrogen fertigation, the highest mean chlorophyll content in garlic leaves (1.57 and 2.65 mg/g FW) at 60 DAP was found with the application of 125% RDN through fertigation, while the lowest mean chlorophyll content (1.01 and 2.19 mg/g FW) was recorded with 75% RDN during 2021-22 and 2022-23, respectively. Likewise, two years pooled data of mean chlorophyll content in leaves at 60 DAP also followed the same trend and significantly higher mean chlorophyll content (2.11 mg/g FW) was recorded in nitrogen at 125% RDN and lowest mean (1.60 mg/g FW) in 75% RDN.

The interaction between saline levels of irrigation water and nitrogen fertigation was found non-significant for chlorophyll content in leaf recorded 60 DAP during both the years of study as well as pooled data of two years.

Table 3: Effect of saline water and nitrogen fertigation on leaf dry matter (%) in garlic at harvest

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	12.17	15.93	16.19	14.76	14.76	16.66	18.47	16.63	13.46	16.30	17.33	15.70
Saline water 2.5 dS/m	10.90	14.53	15.03	13.49	12.26	15.07	16.51	14.61	11.58	14.80	15.77	14.05
Saline water 5.0 dS/m	9.78	12.33	13.07	11.73	10.21	12.81	14.75	12.59	10.00	12.57	13.91	12.16
Mean	10.95	14.26	14.76		12.41	14.85	16.58		11.68	14.56	15.67	
CD at 5%	Irrigation Water (I): 0.41 Nitrogen levels (N): 0.40 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 1.87 Nitrogen levels (N): 0.51 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 0.44 Nitrogen levels (N): 0.21 N at same level of I: NS I at same level of N: NS			

Table 4: Effect of saline water and nitrogen fertigation on chlorophyll content (mg/g FW) in garlic leaf at 60 DAP

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	1.14	1.62	2.14	1.63	2.90	3.02	3.28	3.07	2.02	2.21	2.71	2.35
Saline water 2.5 dS/m	1.06	1.22	1.48	1.25	2.42	2.50	2.74	2.55	1.74	1.86	2.11	1.93
Saline water 5.0 dS/m	0.84	1.00	1.10	0.98	1.26	1.50	1.94	1.57	1.05	1.25	1.52	1.27
Mean	1.01	1.28	1.57		2.19	2.34	2.65		1.60	1.77	2.11	
CD at 5%	Irrigation Water (I): 0.07 Nitrogen levels (N): 0.05 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 0.08 Nitrogen levels (N): 0.05 N at same level of I: NS I at same level of N: NS				Irrigation Water (I): 0.11 Nitrogen levels (N): 0.07 N at same level of I: NS I at same level of N: NS			

3.5 Chlorophyll Index (CI) in leaf at 60 DAP

According to the data presented in Table 5 regarding the chlorophyll index in garlic leaves at 60 DAP, it is evident that different levels of saline water irrigation and nitrogen fertigation had a significant impact on the leaf chlorophyll index at 60 DAP. The chlorophyll index decreased significantly as the saline levels of irrigation water increased. During the years 2021-22 and 2022-23, the mean chlorophyll index in leaves at 60 DAP reached its highest level (34.40 and 36.40%) under canal water which was significantly higher as compared to saline levels of irrigation water. However, the mean chlorophyll index at 60 DAP was lowest (27.93 and 30.13%) under saline water 5.0 dS/m. In the same way, two years pooled data of chlorophyll index at 60 DAP also followed the same trend and significantly higher mean chlorophyll index (35.39%) was recorded in irrigation with canal water and lowest mean (28.86%) in saline water at 5.0 dS/m.

When nitrogen fertigation was applied in both experimental years, the higher mean leaf chlorophyll index at 60 DAP (33.77 and 35.76%) was observed when 125% RDN was applied through fertigation. Conversely, the lower mean chlorophyll index at 60 DAP (30.78 and 28.68%) was observed when 75% RDN was applied during first and second year, respectively. Moreover, two years pooled data of mean leaf chlorophyll index at 60 DAP also followed the same trend and significantly higher mean chlorophyll index (34.60%) was recorded at 125% RDN and lowest mean (29.56%) in 75% RDN.

The interaction between saline water and nitrogen fertigation had a significant effect on chlorophyll index (%) at 60 DAP. Saline water irrigation levels at canal water in combination with 125% RDN nitrogen fertigation recorded significantly higher mean chlorophyll index at 60 DAP (36.77 and 38.57%). which was not statistically at par with at same level of nitrogen fertigation. On the other hand, the minimum mean chlorophyll index at 60 DAP (25.17 and 27.67%) was found at saline water 5.0 dS/m with 75% RDN nitrogen fertigation during 2021-22 and 2022-23 years, respectively, but mean chlorophyll index at 60 DAP (28.45%) at saline water 5.0 dS/m was statistically at par with mean chlorophyll index at 60 DAP (30.60%) at saline water 5.0 dS/m at same level of nitrogen fertigation at 100% RDN during 2021-22 years and two years pooled data of chlorophyll index at 60 DAP also followed the same trend and significantly higher mean chlorophyll index (37.67%) at 60 DAP was recorded in saline water irrigation levels at canal water in combination with 125% RDN and lowest mean (25.92%) in saline water 5.0 dS/m with 75% RDN.

Table 5: Effect of saline water and nitrogen fertigation on chlorophyll Index (%) in garlic leaf at 60 DAP

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	32.23	34.20	36.77	34.40	34.33	36.30	38.57	36.40	33.27	35.24	37.67	35.39
Saline water 2.5 dS/m	28.63	30.60	34.40	31.21	30.33	32.80	36.57	33.23	29.48	31.70	34.99	32.06
Saline water 5.0 dS/m	25.17	28.45	30.13	27.93	27.67	30.60	32.13	30.13	25.92	29.55	31.13	28.86
Mean	28.68	31.10	33.77		30.78	33.23	35.76		29.56	32.16	34.60	
CD at 5%	Irrigation Water (I): 2.02 Nitrogen levels (N): 0.52 N at same level of I: 1.13 I at same level of N: 2.12				Irrigation Water (I): 0.65 Nitrogen levels (N): 0.59 N at same level of I: 1.11 I at same level of N: 1.05				Irrigation Water (I): 1.66 Nitrogen levels (N): 0.42 N at same level of I: 0.91 I at same level of N: 1.76			

Table 6: Effect of saline water and nitrogen fertigation on nitrogen balance index (%) in garlic leaf at 60 DAP

Saline water levels	2021-22				2022-23				Pooled			
	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean	75% RDN	100% RDN	125% RDN	Mean
Canal water	63.6	69.5	78.7	70.6	68.0	74.2	83.2	75.1	65.8	71.9	81.0	72.9
Saline water 2.5 dS/m	59.7	66.8	73.2	66.6	64.7	69.8	75.0	69.8	62.2	68.3	74.1	68.2
Saline water 5.0 dS/m	55.9	60.4	67.8	61.4	60.3	64.8	68.5	64.5	58.1	62.6	68.2	63.0
Mean	59.7	65.6	73.2		64.3	69.6	75.6		62.0	67.6	74.4	
CD at 5%	Irrigation Water (I): 2.1 Nitrogen levels (N): 1.0 N at same level of I: 1.9 I at same level of N: 2.5				Irrigation Water (I): 2.9 Nitrogen levels (N): 1.8 N at same level of I: 3.6 I at same level of N: 3.8				Irrigation Water (I): 2.6 Nitrogen levels (N): 1.1 N at same level of I: 2.3 I at same level of N: 3.0			

3.6 Nitrogen Balance Index (NBI) in leaf at 60 DAP

According to the data on the nitrogen balance index at 60 DAP of garlic leaves (Table 6) indicates that the nitrogen balance index increased significantly as the saline water irrigation levels decreased and recorded significantly highest mean (70.6 and 75.1%) under canal water and lowest mean (61.4 and 64.5%) under at saline water 5.0 dS/m during 2021-22 and 2022-23, respectively. Furthermore, two years pooled data of mean leaf nitrogen balance index at 60 DAP also followed the same trend and significantly higher mean nitrogen balance index (72.9%) at 60 DAP was recorded in irrigation with at canal water and lowest mean (63.0%) in saline water at 5.0 dS/m.

In terms of nitrogen fertigation, the highest mean nitrogen balance index at 60 DAP in garlic leaves (73.2 and 75.6%) was observed with the application of 125% RDN through fertigation, while the lowest mean (64.3 and 59.7%) was recorded with 75% RDN of nitrogen fertigation in during 2021-22 and 2022-23, respectively. Similarly, the two years pooled data of nitrogen balance index at 60 DAP also followed the same trend and significantly higher mean nitrogen balance index (74.4%) at 60 DAP was recorded in nitrogen at 125% RDN and lowest in 75% RDN (62.0%).

However, the nitrogen balance index in garlic leaves was significantly impacted by a combination of saline water and nitrogen fertigation. Irrigation with canal water in conjunction with 125% RDN nitrogen fertigation resulted in considerably greater mean nitrogen balance index in garlic leaves (78.7 and 83.2%), which was significantly higher with the other level of nitrogen fertigation at same level of irrigation water during 2021-22 and 2022-23 years, respectively. Additionally, two years pooled data of nitrogen balance index at 60 DAP also followed the same trend and significantly higher mean nitrogen balance index (81.0%) at 60 DAP was recorded in irrigation with canal water in combination with 125% RDN.

4. Discussion

The results of two years pooled data indicated that the plant height of garlic at 30, 60 DAP were significantly affected by the application of saline water and nitrogen levels through the (Tables 1 and 2). The plant height was maximum under canal water irrigation than saline water level 5.0 dS/m. An average plant height at 30 DAP under canal water was 26.9 cm which was 28.7% higher than the plant height of 20.9 cm under saline water level 5.0 dS/m and plant height at 60 DAP under canal water was 39.8 cm which was 32.7% higher than the plant height of 30.0 cm under saline water level 5.0 dS/m. Similarly, It was observed that onion plant height at highest salt levels more than 4 dS/m gradually decreased and final plants height was severely stunted (Regessa *et al.*, 2022) [29]. The plant height may be limited or totally withdrawn on saline soils due to the three reasons *i.e.*, the toxic effect of gathered ions in the plant tissues, osmotic effect on roots of plant, the specific effect of the basic ions or the combination of all these factors. Razzaque *et al.*, (2021) [28], Ghassemi and Raei (2021) [17], Anjum *et al.*, (2021) [4] and Patel *et al.*, (2020) [27] also reported increased plant height of onion with the decreasing levels of saline water irrigation.

Plant height was significantly affected by the nitrogen fertilizer doses at all the saline water levels applied through fertigation (Tables 1 and 2). The plant height was recorded highest at 125% RDN in all the irrigation water treatments for all the plant growth stages. The plant height increased by 27.9% (30 DAP), 24.8% (60 DAP) at 100% RDN and 39.6% (30 DAP), 33.0% (60 DAP) with the application of 125% RDN over 75% RDN applied through fertigation. This could be due to the tolerable supply of nitrogen, which in turn, pays to better vegetative growth, subsequent in increased plant height. Furthermore, nitrogen plays an important function in the leaves, producing chlorophyll for photosynthesis and advances cell division and growth. The obtained results were similar to the findings of Abera and Adinew (2023) [1], Sisay *et al.*, (2023) [34], Kevlani *et al.*, (2023) [18] and Gashaw (2021) [16] in garlic.

The two years pooled data indicated that dry matter of leafs decreased with increased saline water levels (Table 3). Application of saline water with EC_{iw}=2.5 dS/m and 5.0 dS/m reduced the dry matter of leaves by 10.6% compared to canal water. This reduction might be due to the absorption of salt in the plant body, which closes the plasmodesmata cells and reduces water levels in the plant body, thereby increasing stress caused by higher irrigation water salinity. Decreases in dry weights of leaves could be attributed to excessive salinity stress, which stunts plant growth and reduces leaf development. Similar results were also reported in onion by Anjum *et al.*, (2021) [4], Kiremit and Arslan (2016) [19] and Yohannes *et al.*, (2020) [38]. They reported that the increasing level of salinity reduces fresh and dry mass of leaves.

Dry matter of leaves increased with increasing application of nitrogen from 75% RDN to 125% RDN. The dry matter of leaves increased by 34.2% at 125% RDN over 75% RDN (Table 3). This increase might be due to the proper availability of nitrogen, which increases the photosynthetic rate directly correlated with chlorophyll content in plant cells. This led to an expanded photosynthetic area that enhanced assimilate (dry matter) production and partitioning to the bulbs. Optimal nitrogen fertilizer regimes throughout the growing period promote bulb formation and nutrient translocation from leaves to bulbs, thereby increasing clove dry weight. Sahu *et al.*, (2024) [30] reported the highest dry matter of leaves due to application of the 1.2 IW/CPE with 100% nitrogen level and lowest dry matter yield and dry matter content due to application of the 0.0 IW/CPE with 0% nitrogen level in garlic. Similarly, the maximum leaf dry matter percent recorded with the application of nitrogen fertilizer 105 kg/ha (Tena and Desta, 2023) [36] and 150 kg/ha (Amerian *et al.*, 2024) [3] as compared to control.

Based on two years of pooled data, chlorophyll content, chlorophyll index and nitrogen balance index at 60 DAP were significantly affected by the salinity levels of irrigation water (Tables 4, 5 and 6). According to the pooled data, application of saline water reduced the chlorophyll index by 8.2% and 15.6% and nitrogen balance index at 60 DAP by 6.1% and 14.2% in plots with EC_{iw}=2.5 dS/m and 5.0 dS/m compared to canal water. Similarly, the reduction in chlorophyll content in leaves at 60 DAP was 17.9% and 46.0% with ECiw =25 dS/m and 5.0 dS/m compared to canal water. This reduction might be due to factors such as decreased chlorophyll content and fluorescence, weakening of the protein-pigment-lipid complex, or increased enzyme activity, resulting in a decline in the chlorophyll index. The results suggest that during the vegetative stage, chlorophyll content increases to meet the carbohydrate requirements of the plants. Subsequently, a reduction in chlorophyll content occurs due to the transportation of sugars and carbohydrates towards sinks, along with increased activity of chlorophyllase enzymes leading to chlorophyll degradation. Similar results were also reported by Patel *et al.*, (2024) [26] in Pilli Patti variety of onion with less than 2.0 dS/m levels of salinity and minimum chlorophyll content under Talaja red variety at 8.0 dS/m salinity level. Whereas, Astaneh *et al.*, (2018) [6] observed the highest chlorophyll index due to application of 8 mg/L selenium with 30 mM levels of salinity and minimum chlorophyll index with the application of 8 mg/L selenium and 90 mM levels of salinity in garlic.

Chlorophyll content, chlorophyll index and nitrogen balance index at 60 DAP increased with increasing application of nitrogen. The chlorophyll content, chlorophyll index and nitrogen balance index at 60 DAP increased by 31.9%, 17.1% and 20.0%, respectively, with the application of 125% RDN compared to 75% RDN (Tables 4,5 and 6). This increase might be due to nitrogen's ability to enhance growth characteristics by increasing chlorophyll and nitrogen metabolism. The amount of photosynthetic pigments in leaves increased, with chlorophyll molecules arranged in a ring structure with magnesium ions forming a chelate in the center, leading to enhanced photosynthetic activity and increased chlorophyll content and chlorophyll index. This finding is consistent with the results of Shalaby (2013) [32] and Astaneh *et al.*, (2018) [6], who observed maximum chlorophyll content and chlorophyll index under controlled salinity and four equal splits of the recommended fertilizer dose via fertigation compared to other treatments in garlic. Amerian *et al.*, (2024) [3] also reported increased chlorophyll content with higher levels of nitrogen fertigation in garlic. The present results also confirm the findings of Mansour *et al.*, (2019) [21] who reported the heighest total chlorophyll content with the application of 120 kg/fad nitrogen rate and lowest total chlorophyll content at 90 kg/fad nitrogen rate during the two growing seasons of garlic.

5. Conclusions

The plant height at 30 and 60 days after planting (26.3 and 27.5 cm, 39.3 and 40.4 cm) was recorded significantly higher under irrigation with canal water as compared to other saline water levels, whereas among nitrogen levels, the plant height at 30 and 60 days after planting (26.1 and 28.0 cm, 38.7 and 39.6 cm) was recorded significantly higher under 125% RDN level as compared to other nitrogen fertigation levels during both the years 2021-22 and 2022-23, respectively. Similarly, two years pooled data of also followed the same trend and significantly highest plant height at 30 and 60 days after planting was recorded under application of canal water along with 125% RDN.

The physiological traits of garlic like dry matter (14.76 and 16.63%) at harvest, chlorophyll content (1.63 and 3.07 mg/g FW) and chlorophyll Index (34.40 and 36.40%) at 60 DAP in leaves were recorded significantly maximum under irrigation with canal water as compared to saline water levels EC_{IW} = 2.5 dS/m and 5.0 dS/m. Among nitrogen levels, the dry matter (14.77 and 16.58%) at harvest, chlorophyll content (1.57 and 2.65 mg/g FW) and chlorophyll Index (33.77 and 35.76%) at 60 DAP in leaves were recorded significantly maximum under 125% RDN level as compared to other nitrogen fertigation levels during both the years 2021-22 and 2022-23, respectively. However, pooled data of two years also followed the same trend and significantly higher dry matter, chlorophyll content and chlorophyll Index in leaf were recorded under irrigation of canal water and 125% RDN through fertigation. However, the interaction between saline water and nitrogen fertigation had a significant effect on chlorophyll index in leaves of garlic. Application of canal water along with 125% RDN recorded significantly maximum chlorophyll index in garlic leaves, which was statistically higher as compare to other treatment combinations during both the years 2021-22 and 2022-23, respectively.

The nitrogen balance index (70.6 and 75.1%) in leaves were recorded significantly maximum under irrigation with canal water as compared to other saline water levels. Among nitrogen levels, the nitrogen balance index (73.2 and 75.6%) was recorded significantly maximum under 125% RDN level as compared to other nitrogen fertigation levels (75% and 100% RDN) during both the years 2021-22 and 2022-23, respectively. However, pooled data of two years also followed the same trend and significantly higher nitrogen balance index and carotenoid content were recorded under irrigation of canal water and 125% RDN through fertigation. Based on two years study, it can be concluded that different levels of saline water irrigation and nitrogen application through drip significantly influenced the growth and physiological traits of garlic. To optimize plant growth and physiological characteristics, garlic crop can be irrigated with canal water along with 125% RDN through fertigation also the basal application of recommended dose of phosphorus and potash in the soils.

6. Disclaimer

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

7. Acknowledgement

The authors would like to thank the Department of Vegetable Science, College of Agriculture, CCS Haryana Agricultural University, Hisar 125004, Haryana, India, for financial support and providing the facilities for the research.

8. References

1. Abera T, Adinew A. Effect of nitrogen fertilizer rates on yield components, yield and quality of garlic (*Allium sativum* L.) varieties at Kedidagamela district, Southern Ethiopia. International Journal of Agricultural and Natural Sciences. 2023;16(2):195-206.
2. Ahmad J, Wang H, Song J, Nuerawuti M, Zhang X, Yang W, Ma L, Li XX. The tolerance of an extensive collection of garlic (*Allium sativum* L.) germplasms to salt stress: a sustainable solution to salt stress. Applied Ecology and Environmental Research. 2021;19(3):2281-2303.
3. Amerian M, Khoramivafa M, Palangi A, Gohari G, Ntatsi G. The effect of nitrogen and selenium on some phytochemical characteristics and allicin of garlic leaf. Journal of Horticulture and Postharvest Research. 2024;7(1):77-92.
4. Anjum NN, Anjum AM, Feroze RM, Saeed HM, Shah R, Rafique B, *et al.* Assessment of morphological and biochemical response of different onion cultivars under salt stress conditions. Pakistan Journal of Science. 2021;73(2):306-312.
5. Anonymous. Spices Statistics at spice wise area and production. Spices Board (Ministry of Commerce and Industry, Government of India). 2023-24. Available from: www.indianspices.com
6. Astaneh KR, Bolandnazar S, Nahandi ZF, Oustan S. The effects of selenium on some physiological traits and K, Na concentration of garlic (*Allium sativum* L.) under NaCl stress. Information Processing in Agriculture. 2018;5(1):156-161.
7. Awad-Allah EFA, Attia MG, Mahdy AM. Salinity stress alleviation by foliar bio-stimulant, proline and potassium nutrition promotes growth and yield quality of garlic plant. Open Journal of Soil Science. 2020;10(9):443-458.
8. Bayan L, Koulivand PH, Gorji AG. Garlic: a review of potential therapeutic effects. Avicenna Journal of Phytomedicine. 2014;4(1):1-14.
9. Cai ZQ, Gao Q. Comparative physiological and biochemical mechanisms of salt tolerance in five contrasting highland quinoa cultivars. BMC Plant Biology. 2020;20(70):1-15.
10. Cappellari LR, Gil SS, Palermo TB, Palermo JS, Meneguzzi R, Giordano W, *et al.* Practical method to investigate the effect of volatile organic compounds emitted by rhizobacteria on plant growth under conditions of salt stress. MethodsX. 2023;10(1):1-7.
11. Chinnusamy V, Jagendorf A, Zhu JK. Understanding and improving salt tolerance in plants. Crop Science. 2005;45(1):437-448.
12. El-Saadony MT, Saad AM, Korma SA, Salem HM, Abd El-Mageed TA, Alkafaas SS, *et al.* Garlic bioactive substances and their therapeutic applications for improving human health: a comprehensive review. Frontiers in Immunology. 2024;15(1):1-25.
13. Esmaili E, Kapourchal SA, Malakouti MJ, Homaee M. Interactive effect of salinity and nitrogen fertilizers on growth and composition of sorghum. Plant, Soil and Environment. 2008;54(12):537-546.
14. Ferchichi S, Hessinia K, Aversana ED, Amelia LD, Woodrow P, Ciarmiello LF, *et al. Hordeum vulgare* and *Hordeum maritimum* respond to extended salinity stress displaying different temporal accumulation pattern of metabolites. Functional Plant Biology. 2018;45(1):1096-1109.
15. Frazzoli C, Grasso G, Husaini DC, Ajibo DN, Orish FC, Orisakwe OE. Immune system and epidemics: the role of African indigenous bioactive substances. Nutrients. 2023;15(2):273.
16. Gashaw B. Evaluation of different rates of NPS on growth and yield performances of garlic (*Allium sativum* L.) in Cheha district, Gurage zone, Ethiopia. International Journal of Agronomy. 2021;1(2):1-5.
17. Ghassemi S, Raei Y. Evaluation of ion content, productivity and essential oil quality of garlic under saline conditions and biochar and polyamine treatments. Journal of Food Composition and Analysis. 2021;96(1):1-8.
18. Kevlani L, Leghari Z, Wahocho AN, Memon NUN, Talpur HK, Ahmed W, *et al.* Nitrogen nutrition affect the growth and bulb yield of garlic (*Allium sativum* L.). Journal of Applied Research in Plant Sciences. 2023;4(1):485-493.
19. Kiremit SM, Arslan H. Effects of irrigation water salinity on drainage water salinity, evapotranspiration and other leek (*Allium porrum* L.) plant parameters. Scientia Horticulturae. 2016;201(2):211-217.
20. Lowe H, Steele B, Bryant J, Fouad E, Toyang N, Ngwa W. Important Jamaican medicinal plants with special reference to their antiviral activity. Preprints. 2020:1-20.

21. Mansour F, Ramadan AMM, Metwaly BBMH. Effect of nitrogen fertilization and some stimulants on dry weight, yield, bulb quality and storability of garlic. Zagazig Journal of Agricultural Research. 2019;46(3):621-634.
22. Najman K, Sadowska A, Hallmann E. Evaluation of bioactive and physicochemical properties of white and black garlic (*Allium sativum* L.) from conventional and organic cultivation. Applied Sciences. 2021;11(2):1-24.
23. Nana JB, Abd El Baki HM, Fujimaki H. Determining drought and salinity stress response function for garlic. Soil System. 2024;8(2):1-4.
24. Nazir F, Mahajan M, Khatoon S, Albaqami M, Ashfaque F, Chhillar H, *et al.* Sustaining nitrogen dynamics: a critical aspect for improving salt tolerance in plants. Frontiers in Plant Science. 2023;14(1):1-18.
25. Panse VG, Sukhatme PV. Statistical methods for agricultural research workers. New Delhi: Indian Council of Agricultural Research; 1967.
26. Patel AJ, Vekaria CL, Chauhan HA, Solanki MD. Yield and bio-chemical parameters of onion (*Allium cepa* L.) and consequences of saline irrigation water on it. International Journal of Plant & Soil Science. 2024;36(5):938-946.
27. Patel AJ, Vekaria CL, Sakarvadia HL, Parmar KB, Ponkia HP. Effect of saline irrigation water on growth and yields of onion (*Allium cepa* L.) varieties. International Journal of Chemical Studies. 2020;8(4):966-969.
28. Razzaque AM, Zamil SS, Hasan MM, Siddika M. Effects of salinity on growth, yield and nutrients content of two onion cultivars. Journal of Sher-e-Bangla Agricultural University. 2021;12(2):24-29.
29. Regessa DM, Gemechis OA, Chala EE. Growth, physiology and yield of onion (*Allium cepa* L.) under salt stress. Greener Journal of Agricultural Sciences. 2022;12(2):154-167.
30. Sahu KK, Sharma JC, Sanadya KS. Irrigation and nitrogen fertigation on quality and minerals parameters of garlic (*Allium sativum*) cultivar Solan Selection. Annals of Plant and Soil Research. 2024;26(1):89-96.
31. Shahid MA, Sarkhosh A, Khan N, Balal RM, Ali S, Rossi L, *et al.* Insights into the physiological and biochemical impacts of salt stress on plant growth and development. Agronomy. 2020;10(7):1-34.
32. Shalaby SIM. Effect of irrigation with saline water on development of pink root of garlic. The Egyptian Journal of Phytopathology. 2013;41(2):61-68.
33. Shukla YR, Kaushal M, Bijalwan P. Studies on the effect of macro and micro nutrients on yield and nutrient uptake in garlic (*Allium sativum* L.). International Journal of Current Microbiology and Applied Sciences. 2018;7(10):1201-1204.
34. Sisay TB, Agerchu KJ, Nuraga WG. Effects of bended NPSB fertilizer rates and varieties on growth and yield of garlic (*Allium sativum* L.) in Gummer district, Central Ethiopia. The Scientific Temper. 2023;14(4):17-25.
35. Syamsiah J, Rahayu R, Binafsihi W. Soil properties and shallot yield responses to different salinity levels. Sains Tanah Journal of Soil Science and Agroclimatology. 2020;17(1):30-34.
36. Tena N, Desta B. Influence of nitrogen rates on garlic (*Allium sativum* L.) growth, bulb yield and quality in Debre Berhan, Central Highland of Ethiopia. Berhan International Research Journal of Science and Humanities. 2023;7(1):51-79.
37. Tiwari D, Gautam KA, Kumar R, Sachan S. Effect of different doses of nitrogen and sulphur on growth and yield of garlic. International Journal of Current Microbiology and Applied Sciences. 2019;8(10):1601-1610.
38. Yohannes FD, Ritsema JC, Habtu S, Dam VCJ, Froebrich J. Effect of cyclic irrigation using moderately saline and non-saline water on onion (*Allium cepa* L.) yield and soil salinization in semi-arid areas of Northern Ethiopia. International Commission on Irrigation & Drainage. 2020;13(1):1-13.
39. Zayed O, Hewedy AO, Abdelmoteleb A, Ali M, Youssef MSG, Roumia AF, *et al.* Nitrogen journey in plants: from uptake to metabolism to stress response and microbe interaction. Preprints. 2023:1-31.